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Factors associated with mortality to 21 days of life in dairy heifers in the United States

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Abstract

Results from the first national study of US dairy heifer health indicated that factors associated with mortality in the first 21 days of life included first colostrum-feeding method, timing, and volume; time of separation from dam; calving ease; and twin birth. Population attributable fraction estimates demonstrated the importance of these factors in preventing early calfhood mortality. This analysis indicated that up to 31% of dairy heifer mortality during the first 21 days of life could be prevented by changes in first colostrum feeding method, timing, and volume. Similar analyses for time of separation from dam, calving ease, and twin birth indicated that 16%, 12%, and 3%, respectively, of mortality in the first 21 days of life could be prevented.

Keywords: Dairy heifer; Mortality; Risk factors

1. Introduction

The highest mortality incidence risk occurs during the first 3 weeks of a dairy heifer's life (Waltner-Toews et al., 1986a; Curtis et al., 1988a; Wells et al., 1996). This early mortality represents an important source of economic loss to the dairyman due to loss of the present value of the calf and loss of genetic potential for herd improvement. This time period, therefore, is a critical opportunity period for dairy management.

Understanding relationships between calf-management practices and health in the first 3 weeks of life is critical for producers to take advantage of this opportunity to improve calf health. Factors shown to influence preweaning mortality at the herd level

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include: herd size (Oxender et al., 1973; Jenny et al., 1981; Waltner-Toews et al., 1986b; Lance et al., 1992), season (Martin et al., 1975), aspects of calf housing (Oxender et al., 1973; Waltner-Toews et al., 1986b; Lance et al., 1992) and colostrum feeding management (Oxender et al., 1973; Jenny et al., 1981; Waltner-Toews et al., 1986b), time of calf separation from dam (Jenny et al., 1981), navel treatment (Lance et al., 1992), and the person caring for calves (Jenny et al., 1981). Calf-level management practices shown to play a role in preweaning mortality include: calving ease (Waltner-Toews et al., 1986b), colostrum feeding management (Waltner-Toews et al., 1986b; Perez et al., 1990), calving location (Waltner-Toews et al., 1986b; Curtis et al., 1988b), calf housing (Simensen, 1982; Curtis et al., 1988b; Perez et al., 1990), dam parity and health status (Perez et al., 1990), navel treatment (Waltner-Toews et al., 1986b), administration of vaccines and vitamins ADE (Waltner-Toews et al., 1986b; Curtis et al., 1988b), and twin birth (Simensen, 1982; Nielen et al., 1989).

From the above studies, it is clear that certain management practices can influence neonatal mortality. What is unclear is the relative importance or priority of each of the above factors that could provide a basis for scientifically-sound recommendations about use of appropriate management practices. Further, each of these management factors has an associated economic cost. From a purely economic perspective, minimizing death loss is advantageous only as long as the measures used to do so are cost-effective. Other perspectives (e.g. animal welfare concerns) may also be considered.

The objectives of the analyses of the National Dairy Heifer Evaluation Project data reported here were: (1) to evaluate calf-level management practices associated with mortality within the first 21 days of life for preweaned dairy heifers on US dairy operations; (2) to assess the relative importance of these risk factors in preventing dairy heifer mortality.

2. Materials and methods

The National Dairy Heifer Evaluation Project (NDHEP) was designed to measure baseline calfhood management practices and replacement heifer calf health status for the US dairy heifer population in 1991 and 1992 (Heinrichs et al., 1994). A stratified random sample of dairy herds was selected from US Department of Agriculture—National Agricultural Statistics Service (USDA-NASS) list and area frames in 28 states. Approximately 83% of the US dairy cow population was located in these 28 states. Dairy herds with at least 30 dairy cows were eligible for inclusion in this study.

In the first phase of the study, NASS enumerators visited and collected responses from 1811 dairy producers (Heinrichs et al., 1994). One quarter of the herds was visited in each of the following months: March 1991, June 1991, September 1991, and December 1991. In the second phase, federal or state veterinary medical officers or animal health technicians recorded management information from 1177 respondent operations via questionnaires administered on the operations from 1 to 3 months following the NASS visit. During this study phase, each dairy-calf producer prospectively recorded individual calf births, disease events, deaths, weanings and other removals, and management from birth to weaning for up to 40 liveborn replacement heifers over a 3 month period using a calving log and daily diary card system with standardized data forms. Sampling methods and descriptive results on heifer mortality and morbidity have been reported in an accompanying report (Wells et al., 1996). Recorded calf-level management variables included: twin birth, dam parity, calving ease, calving location, first colostrum feeding method, volume, and timing of delivery to calf, navel dipping, time of separation from dam, and type of calf housing.

To ensure high quality data, each producer was instructed by the visiting federal or state veterinary medical officer or animal health technician about data-recording procedures. These animal health officials administering questionnaires received training prior to the study to standardize data collection and visited participant dairy operations 3 times during the monitoring period to review records, collect data, and respond to data recording questions, and check for possible recording problems. Producer-recorded data were validated and data quality was assessed by the federal or state veterinary medical officer visiting the operation using methods previously described (Wells et al., 1996).

Validated data from the 906 respondent operations with quality data were weighted using methods described previously (Wells et al., 1996) to represent the population sampled: dairy herds of more than 30 milking cows in the 28 sampled states. These operations represented 78% of the national dairy cow population. Herd-level analysis weights were based upon the sampling fraction of herds, adjusted for nonresponse to remove potential effects of bias from nonparticipation to the extent possible. The nonresponse adjustments were made by region, herd size, and season. Calf-level analysis weights were computed as the herd-level analysis weight multiplied by the calf sampling adjustment. The calf sampling adjustment equaled the total number of eligible heifer calves on the operation divided by the number of heifer calves monitored. The reference population was all preweaned dairy replacement heifers on dairy operations with at least 30 dairy cows in the 28 sampled states.

The population of heifer calves monitored was dynamic through the period monitored. Calves entered the monitoring phase at birth and left the study when weaned, removed from the herd, died, lost identification, or when the study ended for that operation. Heifer calves born after the start of monitoring on the operation and at least 20 days before the end of monitoring were eligible for inclusion in the study. Stillbirths were excluded from analysis. Only dairy operations with Holstein as the predominant breed of cattle on the operation were included in this analysis. Calf-level breed information was not available, so final analyses may have included a few non-Holstein calves.

The calf-level outcome of interest was mortality during the first 21 days of life. Herds were stratified by region [1] and herd size [2] for the analyses. Four season categories were created (January–March, April–June, July–September, and October–December) using

[1] Regions included: West—California, Oregon, Washington, Idaho, Colorado; Midwest—Minnesota, Nebraska, Iowa, Wisconsin, Illinois, Indiana, Ohio, Michigan; Northeast—Pennsylvania, New York, Vermont, New Hampshire, Maine, Massachusetts, Connecticut, Rhode Island; Southeast—Maryland, Virginia, North Carolina, Tennessee, Georgia, Alabama, Florida.

[2] Herd sizes included: five or less preweaned dairy heifers on the operation at the time of the first herd visit; 6–15 preweaned dairy heifers; 16 or more preweaned dairy heifers.

the month of birth for each calf monitored to evaluate associations between dairy calf mortality and season. Since interactions between first colostrum feeding method, timing, and volume were biologically plausible and anticipated, a multiple-level categorical variable was created to incorporate this in further analyses.

Relationships between preweaning mortality and calf-level management were evaluated using specialized software for survey data analysis (SUDAAN User's Manual, 1990). This software accounts for sample design stratification and within-herd clustering when variances are estimated—unlike usual risk factor analyses, which assume simple random sampling. SUDAAN computes variances by first forming the Taylor series linearization for each statistic, which are then substituted into the formula for computing the variance appropriate for the design specified by the user. Eligible variables were first screened in SUDAAN using log-linear chi-square tests of independence (test for no interaction in the log-linear model fit to the log of estimated cell proportions). Variables with chi-square test statistics that resulted in P-values less than 0.2 were eligible for SUDAAN-based logistic regression modelling. Region and herd size were forced into the logistic regression model as fixed effects. From the multiple logistic regression model, odds ratios (OR) with 95% confidence limits were computed.

Estimation of the importance of key variables in the national population (i.e. population attributable fraction, PAF) was computed using the multivariable methodology described by Bruzzi et al. (1985). The formula used was

$$\mathrm{PAF} = 1 - \Sigma_j (p_j / R_j)$$

where p_j is the proportion of all deaths in stratum j and R_j is the estimated relative risk in stratum j. Multivariable odds ratios were used to approximate relative risks and the proportion of calf deaths per stratum was estimated from weighted cross-tabulations. This methodology requires that, within each variable, the stratum with the lowest risk be the reference level. In addition, the summary PAF was computed, with the formula above but using the proportion of deaths and odds ratios across all strata within variables from the logistic model.

Estimated upper bounds for the PAF for each variable were estimated by computing the PAF (as described above) using the upper 90% confidence limit of the odds ratios for each stratum simultaneously. Since it is unlikely that each stratum for a variable would be at the highest level simultaneously, the 90% confidence limit was utilized instead of the 95% confidence limit. Estimated lower bounds for each PAF were computed similarly, using the lower 90% confidence limits of the odds ratios.

3. Results

There were 9484 preweaned dairy heifer calves from 829 dairy operations included in the analysis. The univariable screening procedure identified four variables associated with dairy heifer mortality in the first 21 days of life: twin birth, calving ease, first colostrum feeding method, timing, and volume, and timing of calf separation from dam (Table 1). These variables, along with the forced variables (region and herd size), were included in the logistic-regression model.

Table 1
Percentage of preweaned heifer calves and deaths by variable and univariable association with 21-day mortality (weighted analysis)

Variable	Level	Percentage of calves	P [a]	Percentage of deaths
Region	West	25.1	0.96	26.9
	Midwest	45.6		44.4
	Northeast	17.7		17.8
	Southeast	11.6		10.9
Herd size	< 6 preweaned heifers	27.5	0.54	33.2
	6–15	31.6		29.2
	> 15	40.9		37.6
Season of birth	Winter	23.2	0.46	29.7
	Spring	32.3		28.5
	Summer	25.8		22.1
	Fall	18.7		19.7
Twin birth	Yes	3.7	0.05	6.6
	No	96.6		93.4
Dam parity	1st calf	29.5	0.66	33.4
	2nd or 3rd calf	41.8		37.8
	4th or greater calf	28.6		28.8
Calving ease	No assistance	80.3	0.13	71.1
	Easy pull	13.8		18.4
	Hard pull	4.2		5.6
	Forced extraction	1.7		4.9
Calving location	Freestall	3.6	0.70	4.0
	Individual area in building	24.6		31.1
	Multiple area in building	18.4		17.2
	Tie stall or stanchion	13.5		10.5
	Drylot	20.4		21.2
	Pasture	19.4		16.0
First colostrum feeding	Nursing < 6 h	22.4	0.01	28.8
	Nursing 6–12 h	5.8		5.4
	Nursing ≥ 13 h	0.7		1.1
	Bucket < 6 h ≤ 2 qts	31.2		26.6
	Bucket < 6 h > 2 qts	10.8		8.4
	Bucket ≥ 6 h ≤ 2 qts	16.4		13.2
	Bucket ≥ 6 h > 2 qts	6.0		3.8
	Eosph. feeder < 6 h ≤ 2 qts	1.8		1.9
	Eosph. feeder < 6 h > 2 and < 4 qts	1.4		3.9
	Eosph. feeder < 6 h ≥ 4 qts	1.0		1.0
	Eosph. feeder ≥ 6 h ≤ 2	0.4		0.3
	Eosph. feeder ≥ 6 h > 2 and < 4 qts	1.3		0.6
	Eosph. feeder ≥ 6 h ≥ 4 qts	0.3		1.0
	No colostrum	0.2		4.1
Navel dipping	With iodine	53.0	0.43	57.2
	None or non-iodine dip	47.0		42.8
Separation from dam	0 h and before nursing	18.8	0.09	16.4
	< 12 h	50.2		46.8
	12–24 h	25.1		22.8
	> 24 h	5.8		14.1

Table 1 (continued)

Variable	Level	Percentage of calves	P [a]	Percentage of deaths
Calf housing	Calf hutch	42.3	0.42	40.6
	Group pen in calfbarn/superhutch	6.4		7.8
	Individual pen in cowbarn	10.5		12.1
	Group pen in cowbarn	6.6		6.1
	Tied in cowbarn	8.4		13.4
	Individual pen in calfbarn	21.1		17.6
	Tied in calfbarn	4.7		2.3

[a] P-value from log-linear χ^2 tests of independence between independent variables and dairy heifer mortality, adjusted for study design stratification and within-herd clustering using SUDAAN.

Table 2
Mortality risk factors within the first 21 days of life for US preweaned dairy heifers, 1991–1992

Variable	Level	Odds ratio	95% CL
Region	West	2.08	1.13–3.82
	Midwest	1.31	0.66–2.62
	Northeast	1.49	0.71–3.14
	Southeast	1.0	–
Herd size	< 6 preweaned heifers	1.62	0.92–2.86
	6–15	1.12	0.66–1.91
	> 15	1.0	–
Twin birth	Yes	1.94	1.03–3.66
	No	1.0	–
Calving ease	Unassisted	1.0	–
	Easy pull	1.55	0.77–3.11
	Hard pull	1.62	0.78–3.35
	Extraction	4.22	1.31–13.6
First colostrum feeding	Nursing < 6 h	1.85	0.59–5.84
	Nursing 6–12 h	1.31	0.38–4.55
	Nursing ≥ 13+ h	1.82	0.38–8.88
	Bucket < 6 h ≤ 2 qts	1.20	0.43–3.38
	Bucket < 6 h > 2 qts	1.0	–
	Bucket ≥ 6 h ≤ 2 qts	1.21	0.38–3.86
	Bucket ≥ 6 h > 2 qts	1.03	0.30–3.50
	Esoph. feeder < 6 h ≤ 2 qts	1.46	0.38–5.61
	Esoph. feeder < 6 h > 2 and < 4 qts	5.73	2.06–16.0
	Esoph. feeder < 6 h ≥ 4 qts	1.04	0.32–3.32
	Esoph. feeder ≥ 6 h ≤ 2 qts	1.15	0.16–8.35
	Esoph. feeder ≥ 6 h > 2 and < 4 qts	1.15	0.23–5.83
	Esoph. feeder ≥ 6 h ≥ 4 qts	9.67	2.84–32.8
	No colostrum	74.12	11.3–487
Separation from dam	At birth before nursing	1.09	0.52–2.30
	< 12 h	1.12	0.69–1.82
	12–24 h	1.0	–
	> 24 h	3.19	1.47–6.93

Table 3
Population attributable fractions (PAF) for mortality risk factors within the first 21 days of life for US preweaned dairy heifers, 1991–1992

Variable	PAF	Estimated lower bound [a]	Estimated upper bound [a]
Region	0.30	−0.15	0.56
Herd size	0.16	−0.11	0.33
Twin	0.03	0.01	0.05
Calving ease	0.12	−0.02	0.20
First colostrum feeding	0.31	−0.08	0.85
Separation from dam	0.16	−0.22	0.39
All six risk factors	0.72		

[a] Estimated using lower and upper 90% confidence limits of odds ratio values of each stratum within variable simultaneously.

Twin calves were 1.9 times more likely than singletons to die within the first 21 days of life (Table 2). Calves that were delivered by forced extraction were 4.2 times more likely to die within the first 21 days of life compared with calves born unassisted. Calves that received no colostrum were 74 times more likely to die by 21 days of life compared to calves that received more than 2 quarts of colostrum by bucket or bottle in the first 6 h after birth. Other first-colostrum delivery methods associated with higher risk of mortality included feeding 2–4 quarts of colostrum within 6 h of life via esophageal feeder ($OR = 5.7$) and feeding more than 4 quarts of first colostrum after 6 h of age via esophageal feeder ($OR = 9.7$). Separating calves from their dams after 24 h of life was another factor associated with increased odds of mortality ($OR = 3.2$, compared with the reference level of separation at 12–24 h of life).

The summary PAF was 0.72. This estimate means that up to 72% of total dairy heifer mortality up to 21 days of life in the reference population could be prevented by removing from the baseline the increased death loss associated with twin birth, calving ease, first colostrum feeding method, timing, and volume, timing of calf separation from dam, region, and herd size.

The variable with the greatest importance was first colostrum feeding method, timing, and volume; its PAF was 0.31 (Table 3). This is interpreted as: up to 31% of total dairy heifer mortality up to 21 days of life could be prevented by removing the increased death loss associated with colostrum feeding methods that are different from the baseline (bucket or bottle feeding greater than 2 quarts of colostrum within 6 h of life). Timing of separation from dam was the second most important management variable for controlling calf death loss to 21 days of life, as its PAF was 0.16.

4. Discussion

This was the first national study of neonatal mortality risk factors in US dairy heifers with the largest number of dairy heifers monitored to date. The rigorous sampling methods provided good external validity to the national US population of calves. Because of the survey design with explicit methods and reference population, this study allowed a unique opportunity to assess not only the strength of associations between risk factors and mortality (i.e. odds ratios) but also the importance of these assumed causal associations, using PAF methods. Population attributable fraction methodology for logistic models (to allow for the multivariable causation of mortality) has been described but the benefits of this methodology have not been widely captured to date in interpreting results from veterinary studies. The methodology used (Bruzzi et al., 1985) provides a relatively straightforward estimation of PAF from multivariable analyses, therefore allowing adjustment for confounding, incorporating the estimated relative risks and distribution of deaths within variable strata.

Certain limitations restrict interpretation of study results. First, dairy-heifer mortality is caused by many factors—certainly exceeding those evaluated in this study. The objective of this study was to evaluate some of the key management factors that can be changed by herd managers, as previously described in the scientific literature. Second, incorporation of interactions among explanatory variables in analysis was restricted to that of first colostrum feeding method, timing, and volume. Other interactions, while feasible, were considered biologically less important and not included since inclusion would have made analyses computationally intense and extremely difficult to interpret. Third, only pseudo-confidence intervals for the PAF estimates were provided as the methodology for estimating the exact variance of these parameters in the context of surveys with complex study designs requiring weighting has not been developed. To give an estimate of the variability of the population attributable fraction estimates, the lower and upper 90% confidence limits for the odds ratios for each stratum were computed. This probably gives an overly conservative (broad) estimate of the variability in the PAF estimate, since it is unlikely that each stratum for a variable would be at the lowest (or highest) level simultaneously. Negative PAF values (e.g. lower confidence limits) were interpreted as protective effects—that is, the percentage of total US dairy heifer mortality that could be caused (increased) by removing the effects of a variable.

Despite the above constraints, the results from this study are very useful to dairy heifer calf raisers, in both providing estimates of the strength of associations between management factors and neonatal mortality and providing estimates of the importance of these factors in the U.S. dairy calf population. Population attributable fraction is interpreted as the proportion of deaths preventable if the effect of a factor of interest is removed. This provides a clear picture of both the relative and absolute value of certain management practices in the prevention of neonatal mortality. It is not possible to simply add estimates of population attributable fraction across the factors to obtain an overall estimate of preventable mortality since the factors are not disjoint. Since each causal pathway for mortality may have a series of necessary factors for causation, the same factor may be necessary in more than one causal pathway.

If the risk factors are statistically independent and there are no interactions in the logistic model, then the complement of the summary PAF is the product of the complements of the individual PAF values (Bruzzi et al., 1985). The calculation of the summary PAF for the data in this study assuming this simplified situation was 0.71, agreeing very closely with the estimate of 0.72 described. This is an indication that there were no significant interactive effects between variables — substantiating the decision to omit them from the logistic regression analysis.

Consistent with published literature (Gay, 1983), lack of colostral feeding was highly associated with neonatal death loss. Many different combinations of first colostral feeding method, timing, and volume were not significantly different from the baseline—an indication that several ways to feed first colostrum can be effective. The reason for higher death loss with esophageal feeding at certain times and volumes was not immediately clear. Esophageal feeding, the routine practice on 2.3% of dairy operations (United States Department of Agriculture—Animal and Plant Health Inspection Service Veterinary Services, 1993), is often recommended for calves unable to consume at least a minimum amount of colostrum to ensure its delivery and to speed the process (Gay, 1984). One explanation for the elevated risk may be that some of the calves fed via esophageal feeder may have been unhealthy due to other unmeasured factors. These unmeasured factors, however, exclude those associated with twin birth, calving ease, or time of separation from dam, as these effects were adjusted for in the logistic regression model. Of the 6.3% of all dairy heifers fed first colostrum via esophageal feeder, 33% (2.1% of all heifers) were from operations where the routine first colostrum feeding practice was reportedly via bucket, bottle, or nursing. This 2.1% of all dairy heifers experienced a higher risk of death (7.8% mortality by 21 days) compared to those fed via esophageal feeder from operations where esophageal feeding was the routine method of delivery of first colostrum (4.1%). This suggests that the condition of these calves warranted esophageal (forced) feeding. Keeping in mind this potential bias, the PAF estimate of 0.31 for first colostrum feeding may be somewhat biased upwards relative to its true value. It is also possible that esophageal feeding itself may in some cases create health problems, for example through improper techniques or lack of esophageal feeder sanitation between calves.

Time of calf separation from dam accounted for 16% of mortality. This is consistent with results previously reported which related routine herd-level practice of time of separation from dam to calf mortality (Jenny et al., 1981). This is likely related to the fact that calves remaining with their dams for more than one day are exposed to a greater load of pathogens than those removed to a separate calf-raising area during the first day of life. As evidence for this increased exposure, Quigley et al. (1994) have shown associations between fecal shedding of certain pathogens and housing near the dam during the first 3 days of life.

Another important factor that plays a role in mortality to 21 days of life includes calving ease. Waltner-Toews et al. (1986b) also reported similar results. Forced extraction leads to increased stress on the newborn calf and may delay ingestion of colostrum and subsequent passive transfer of immunoglobulins.

Twinning also plays a role in determining neonatal calf mortality. Previous studies have shown mortality in the first 24 h of life to be higher among twins (Simensen, 1982; Nielen et al., 1989). Reasons may include shorter gestation lengths (Nielen et al., 1989), smaller birthweight, and greater incidence of dystocia (Gregory et al., 1990).

5. Conclusions

Results from the first statistically-based national study of risk factors for neonatal dairy heifer mortality in the US indicate that first colostrum feeding method, timing, and volume is critical in preventing mortality. Removing the effects of colostrum management could prevent up to 31% of mortality in dairy calves to 21 days of age. Another important factor is timing of calf separation from her dam. The population attributable fraction for this variable was 16%. Calving difficulty (12% of mortality) and twinning (3% of mortality) also contribute to mortality to 21 days of life. These results were based on a national sample of over 9484 Holstein replacement dairy heifers monitored from birth to weaning or death.

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